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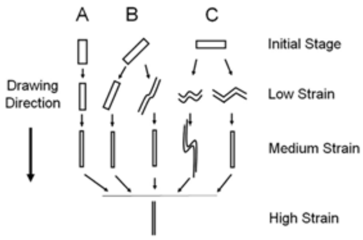
Hierarchical structures in cold-drawn pearlitic steel wire

Xiaodan Zhang[1,2], Andrew Godfrey[1], Niels Hansen[2], Xiaoxu Huang[2]

Aim: Quantify the microstructure and crystallography of drawn pearlitic steel wires following the previous analysis of strengthening mechanisms and strength structure relationships.

Experimental: Five samples at five strains (0, 0.68, 1.51, 2.67, 3.68) of near-eutectoid composition steel with a carbon content of 0.8 wt%, characterized by SEM, EBSD, TEM and nano beam diffraction (NBD).

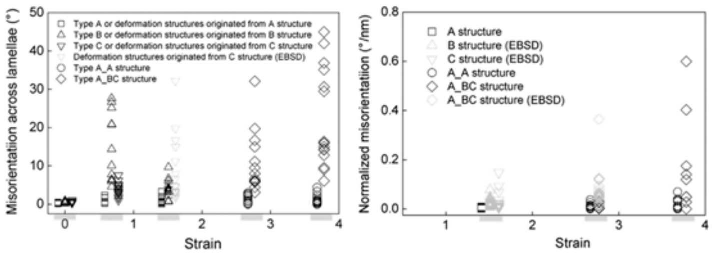
1. Hierarchical structural evolution



A_A has its origin in A colonies; A_B, A_C and A_BC have their origins in B and C colonies; a clear distinction between A_B and A_C structures is no longer possible and they are classified together as an A_BC structure..

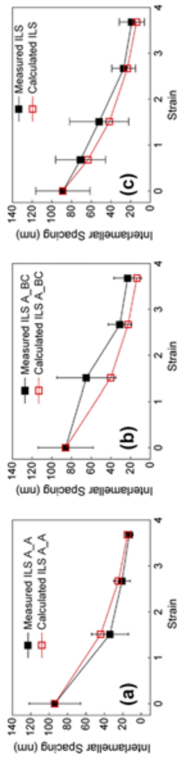
(1) from an A to an A_A structure where cementite lamellae in A form an angle of 0–30° with the wire axis and A_A is characterized by relatively small changes in misorientation angle along and across the ferrite lamellae;
(2) from a B and a C structure to A_BC structure where cementite lamellae in B or C form an angle of 30°–90° with the wire axis and A_BC is characterized by relatively large changes in misorientation angle along and across the ferrite lamellae.

2. Angular changes across (L) and along (R) ferrite lamellae



The orientation changes observed in the initial structure (A, B and C) are comparable and are less than 1°. For small and medium strains, large misorientation angles characterize B and C structures, and to a lesser extent the A structure. At strains larger than 1.5 this difference is observed indicating that although the morphology in A_A and A_BC structures appear uniform, the large angular spread introduced at low and medium strains in the A_BC structure persists to the largest strain.
The value and spread of normalized misorientation angles along the ferrite lamellae increases with strain for all structures, and is significantly larger in the A_BC structure than in the A_A structure.

3. Interlamellar spacing (ILS)



ILS with increasing strain is assumed to follow a power law relationship agrees well with the experimental finding for A_A structure but significantly underpredicts the ILS for the A_BC structure. When the numbers are combined and taking into account that the standard deviations are fairly large, it appears that an analysis based on average values and on a power law relationship gives a reasonable description of the structural refinement of the lamellar structure at increasing strain.

4. Conclusion and outlook

The structural evolution is hierarchical as the structural variations are caused by a different macroscopic orientation of the cementite in the initial (patented) wire. These variations subdivide the lamellar structure into two types, A_A and A_BC, where the latter has a larger ILS, a higher dislocation density and In parallel high-angle boundaries parallel to the cementite lamellae. In both structures the dislocations are stored in the ferrite lamellae as individual dislocations and in the form of low-angle cell boundaries.
Future work will focus on the microstructure and strengthening mechanisms to larger strains, finer structures and a flow stress about 5-6 GPa and to annealed nanostructures.

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The microstructure and crystallography of drawn pearlitic steel wires have been quantified by a number of electron microscopy techniques including scanning electron microscopy, transmission electron microscopy, electron backscatter diffraction and nanobeam diffraction, with focus on the change in the structure and crystallography when a randomly oriented cementite structure in a patented wire during wire drawing is transformed into a lamellar structure parallel to the drawing axis. Changes in the interlamellar spacing and in the misorientation angle along and across the ferrite lamellae show significant through-diameter variations in wires drawn to large strains $\geqslant 1.5$. The structural evolution is hierarchical as the structural variations have their cause in a different macroscopic orientation of the cementite in the initial (patented) structure with respect to the wire axis. The through-diameter variations subdivide the lamellar structure into two distinctly different types: one (called A_A) has a smaller interlamellar spacing and smaller dislocation density than the other (called A_BC). During drawing, the thickness of the ferrite and cementite lamellae are reduced to 20 and 2 nm, respectively, and high-angle boundaries form in the A_BC structure parallel to the cementite lamellae. The structural and crystallographic analyses suggest that boundary strengthening and dislocation strengthening are important mechanisms in the cold-drawn wire. However, differences in structural parameters between the A_A and the A_BC structure may affect the relative contributions of the two mechanisms to the total flow stress.

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References

1. Xiaodan Zhang, Andrew Godfrey, Niels Hansen, Xiaoxu Huang. Hierarchical structures in cold-drawn pearlitic steel wire. Acta Mater. 2013; 61: 4898-4909.
2. Xiaodan Zhang, Andrew Godfrey, Xiaoxu Huang, Niels Hansen, Qing Liu. Microstructure and strengthening mechanisms in cold-drawn pearlitic steel wires. ACTA MATERIALIA, 2011, 59, 3422-30.
3. Xiaodan Zhang, Andrew Godfrey, Niels Hansen, Xiaoxu Huang, Wei Liu, Qing Liu. On The evolution of cementite morphology in a pearlite steel wire during wet wire drawing. MATERIALS CHARACTERIZATION, 2010, 61, 65-72.
4. Xiaodan Zhang, Andrew Godfrey, Wei Liu, Qing Liu. Study on dislocation slips in ferrite and cementite deformation in cold-drawn pearlitic steel wire from medium to high strain. MATERIALS SCIENCE AND TECHNOLOGY, 2011, 27, 562-7.
5. Xiaodan Zhang, Andrew Godfrey, Xiaoxu Huang, Niels Hansen, Wei Liu, Qing Liu. Characterization of the microstructure in drawn pearlitic steel wires. Risoe International Symposium on Materials Science. Proceedings 30, 2009. p. 409-416.
6. Xiaodan Zhang, Niels Hansen, Andrew Godfrey, Xiaoxu Huang. Microstructural evolution, strengthening mechanisms and strength structure relationship in cold-drawn pearlitic steel wire. Proceedings of the 33rd Risø international symposium on materials science: nanometals—status and perspectives. 2012: 407-416.